Overview of Gridscale Rampable Intermittent Dispatchable Storage (GRIDS) Program

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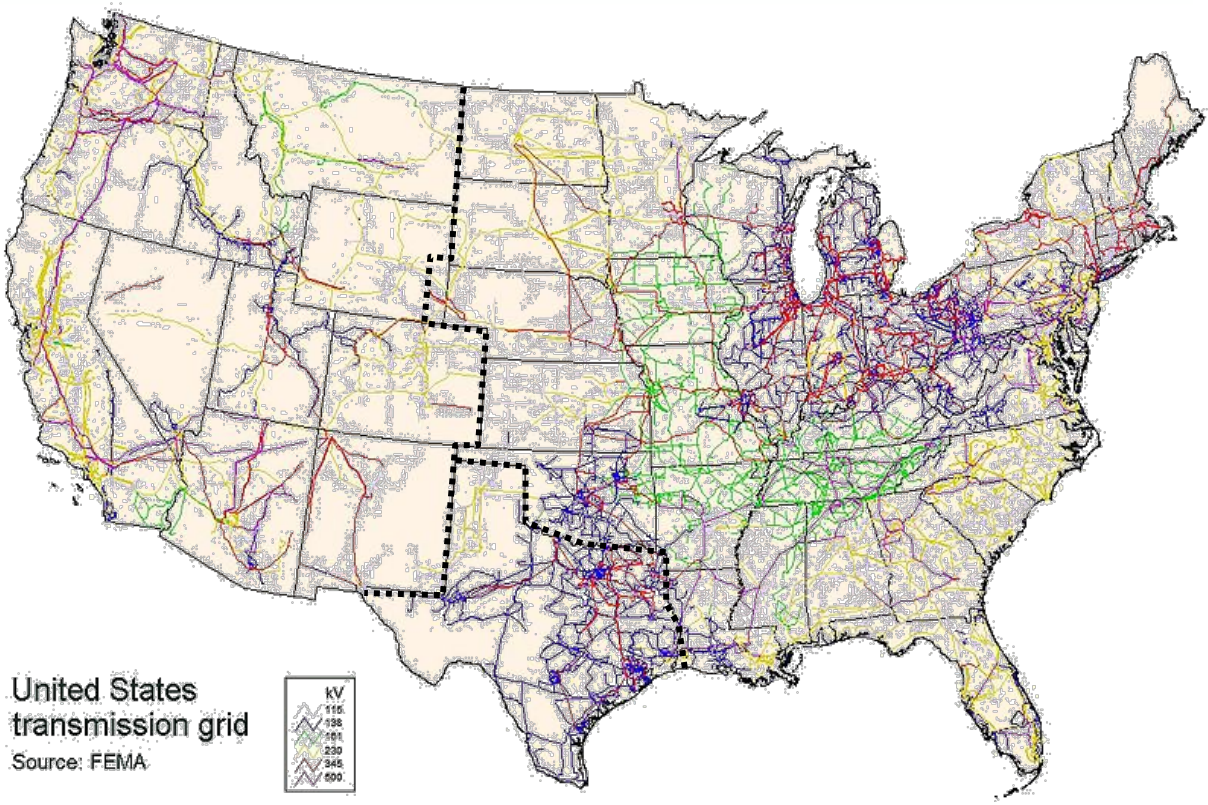
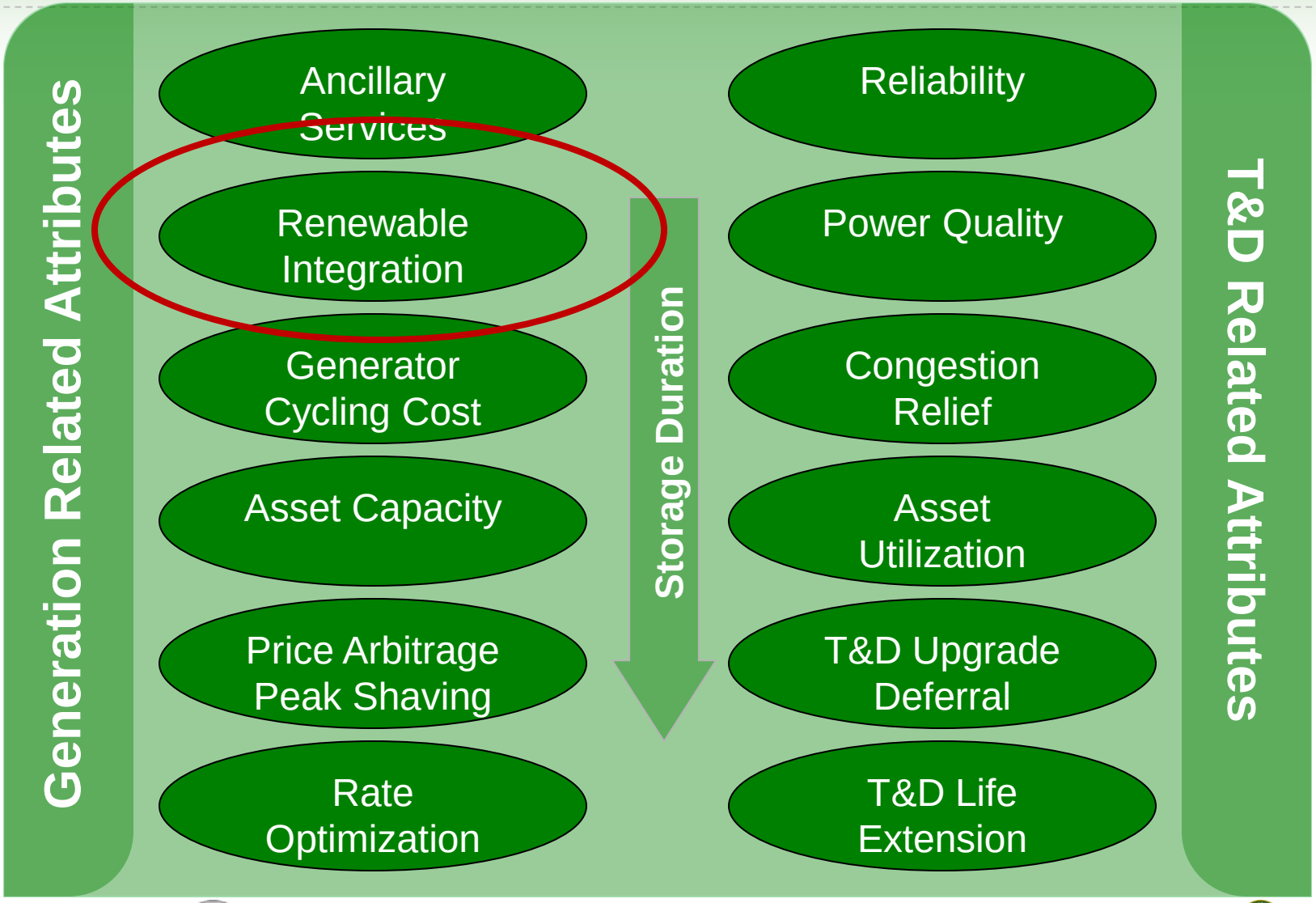
Power Grid: Large Supply Chain With No Warehouse

- Electrification: Premier Engineering Accomplishment of the 20th Century [NAE]
- Harnessing Renewable Power: #1 Challenge for 21st Century
- Limited Storage

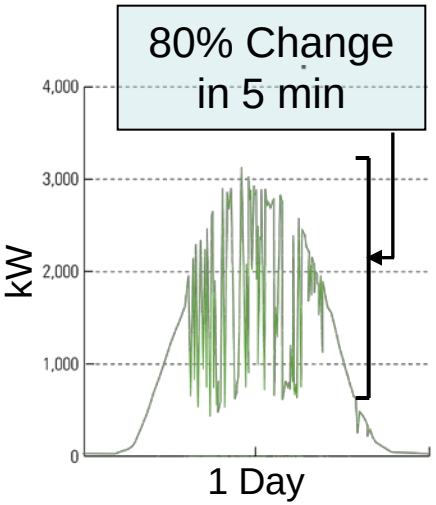


Electric Energy Storage Applications

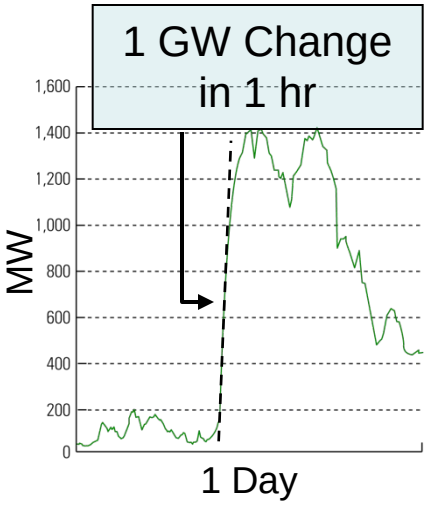


Storage For Firming Renewables

Solar PV in AZ (TEP)



Wind in OR (BPA)

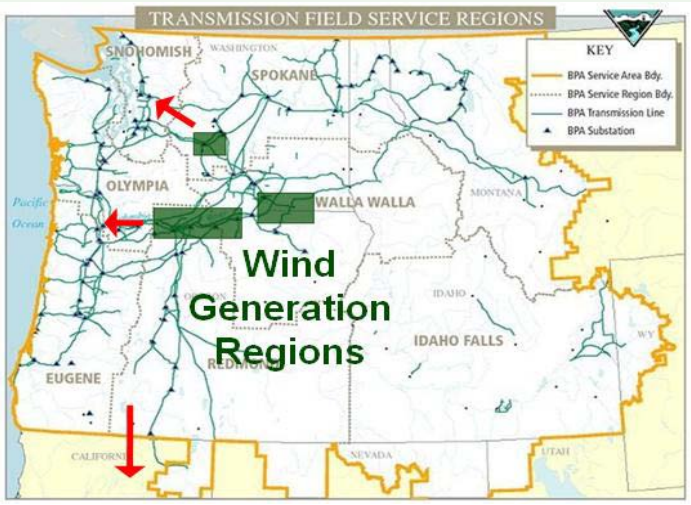


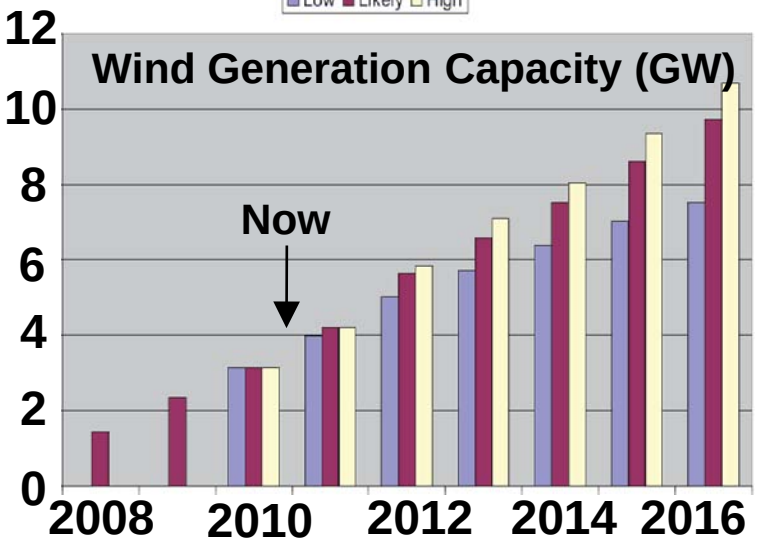
Problem:
Minutes-to-Hours Changes in Power

Need: Grid Storage that is Dispatchable and Rampable
ARPA-E: Energy Storage to Enable High Penetration of Renewables

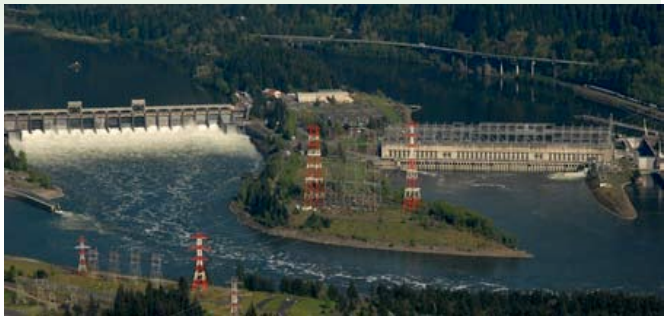
High Renewable Generation Integration

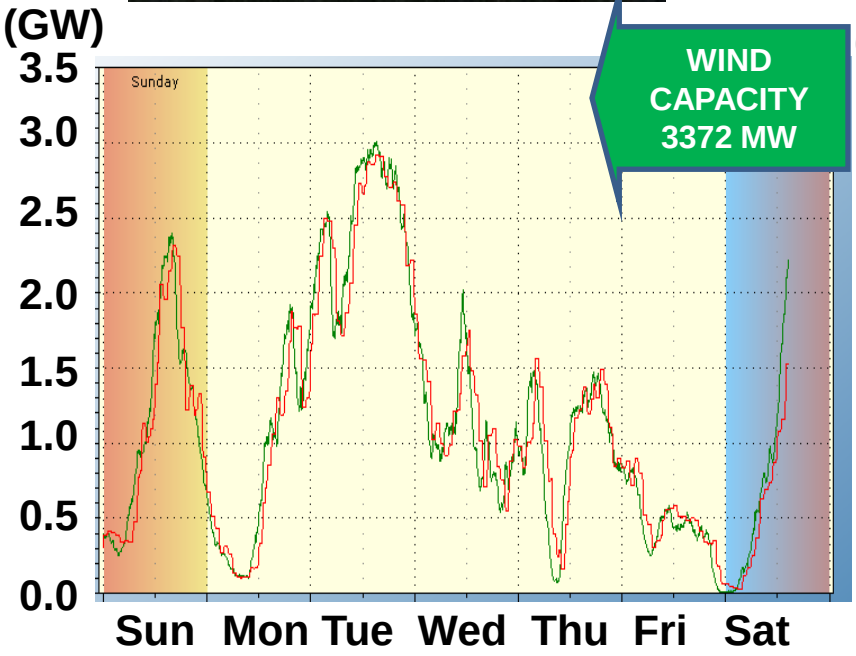
- Larger Balancing Authority
- Increase Transmission Capacity
- Improved Situational Awareness
  - Real Time Knowledge
  - Improved Weather Models
  - Generation Protocols
- New Storage Technologies



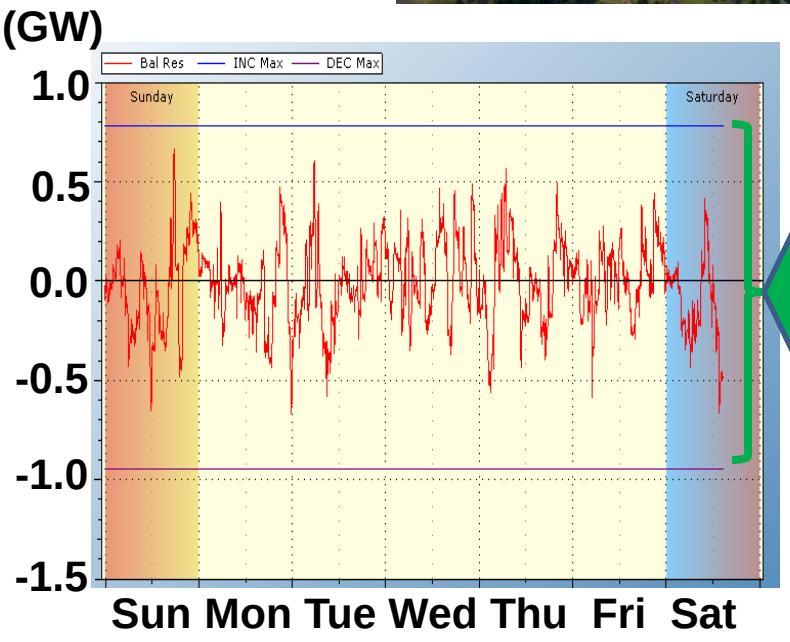


Wind Generation and Balancing Storage in High Renewable Penetration Regions





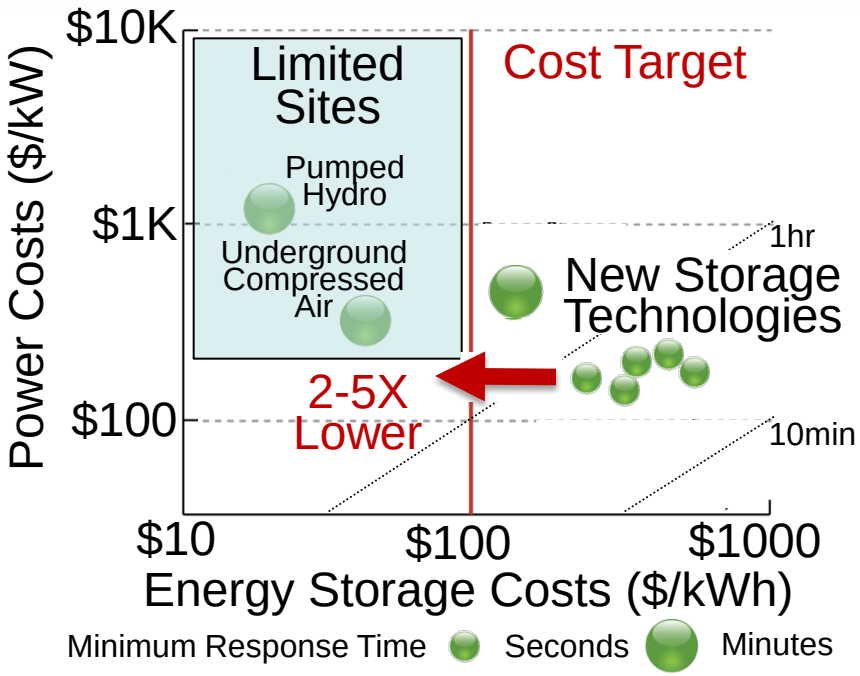
WIND CAPACITY 3372 MW



HYDROPOWER RANGE 1600-2000MW

System Challenge: Efficient Energy Storage at Minutes to Hours Duration to Firm Ramping Balance

Grid-scale Rampable Intermittent Dispatachable Storage (GRIDS) Metrics



Economics of Hydro / Deployable Anywhere

Technology Agnostic:
Chemical, Mechanical, Electromagnetic

Connect Across Industry for Handoffs

Focus: Transformational approaches to energy storage to enable low cost

New Technology Need: Cost-Effective Energy Storage Solutions

Portfolio of Projects

UNIVERSITY/ LAB

USC UNIVERSITY OF SOUTHERN CALIFORNIA

Rechargeable Fe-Air Battery

Berkeley Lab

Advanced Flow Battery

CUNY The City University of New York

Rechargable $Zn\text{-}MnO_2$ Battery

SMALL BUSINESS

PRIMUS POWER Smart Grid Storage

New Flow Battery Electrode

FLUIDIC ENERGY

High Power Metal-air Storage

Proton ENERGY SYSTEMS

Neutral Water Fuel Cell

Beacon POWER

Long Duration Flywheel

GENERAL COMPRESSION expanding clean power

Fuel-Free Isothermal Compression

CORPORATION

United Technologies Research Center

Advanced Flow Battery

GENERAL ATOMICS AND AFFILIATED COMPANIES

Soluble Lead Flow Battery

ABB

2G-HTS SMES

BOEING

High-Energy Flywheel

Transformative Electrochemical Flow Storage System

United Technologies Research Center

Clipper

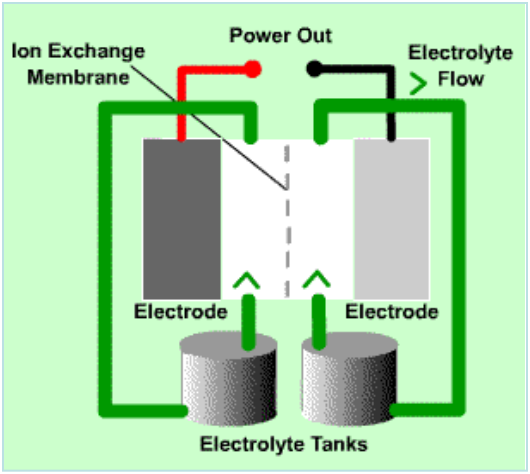
Pratt & Whitney
A United Technologies Company

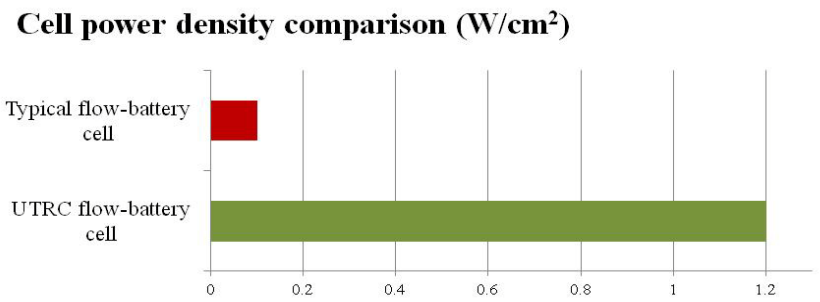
Pratt & Whitney Rocketdyne, Inc.

A unique flow battery cell that provides 10X increase in power density

Novel cell design will reduce system cost by 2-4X

Jump-starts domestic effort in redox flow batteries, which had migrated out of North America





Rechargeable Iron-Air Battery

Cell Reaction:

$Fe + H_2O + ½\ O_2 \Leftrightarrow Fe(OH)_2$

Anode: *(discharge)*

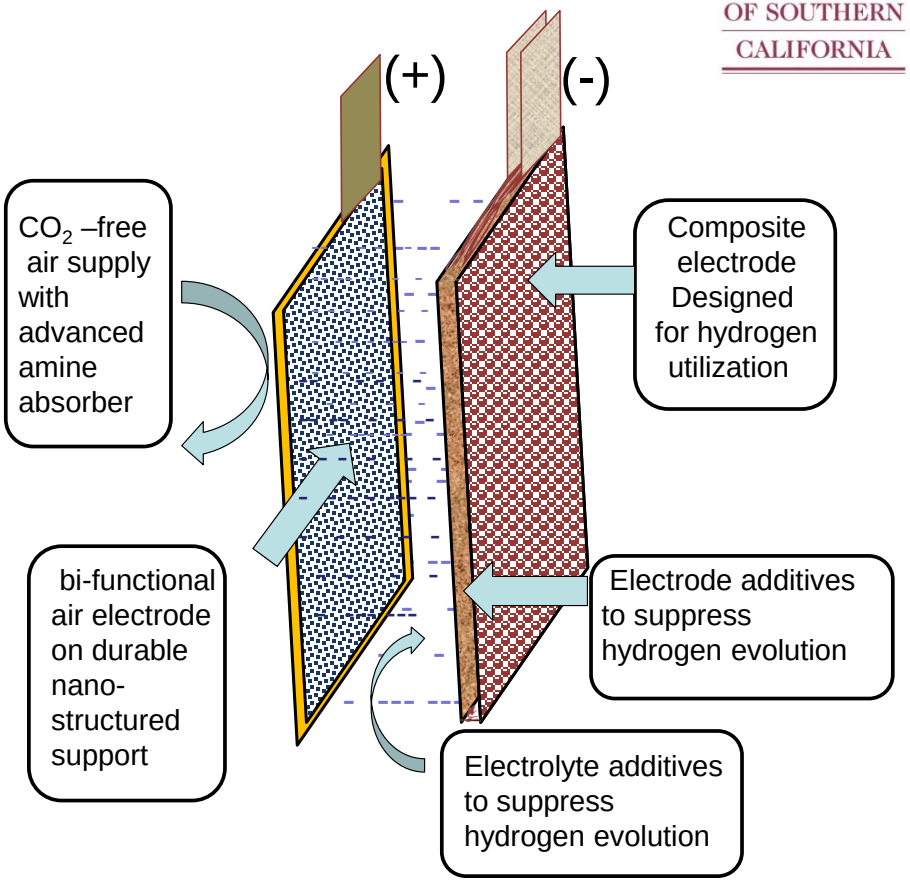
$Fe + 2OH^- \Rightarrow Fe(OH)_2 + 2e^-$

Cathode: *(discharge)*

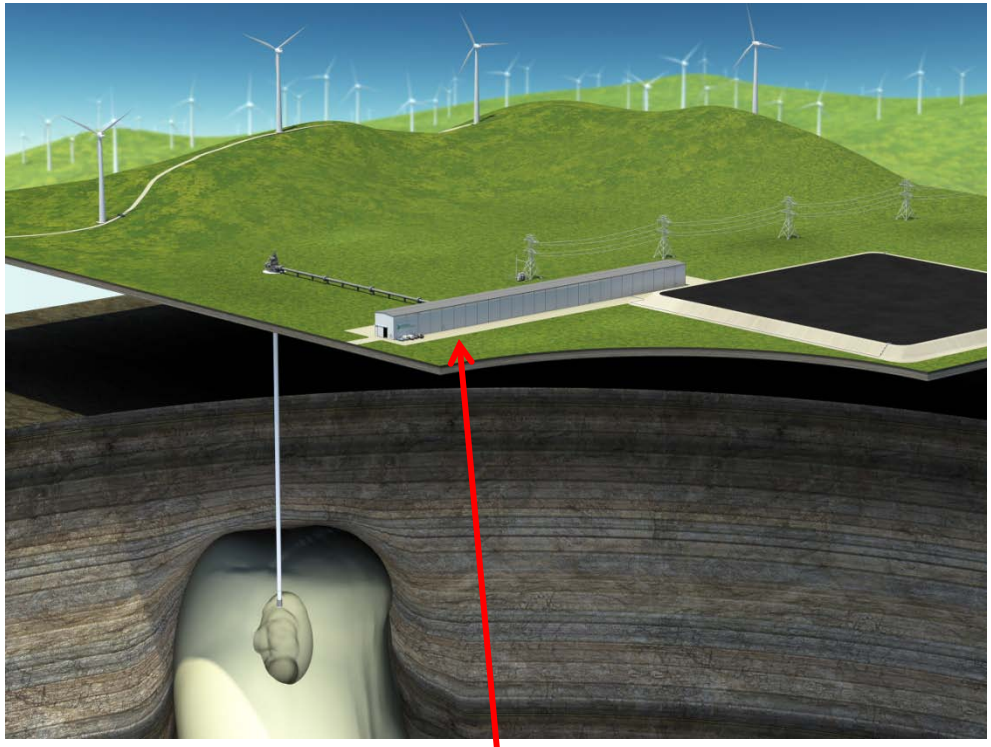
$½\ O_2 + H_2O + 2e^- \Rightarrow 2OH^-$

< $100/kWh & >5000 cycles high power, low cost, electrochemical storage

"Iron is Cheap, Air is Free"



Fuel-Free Isothermal Compressed Air Storage



Innovative Technology:
New Isothermal Compressor / Expander

GENERAL COMPRESSION
expanding clean power™

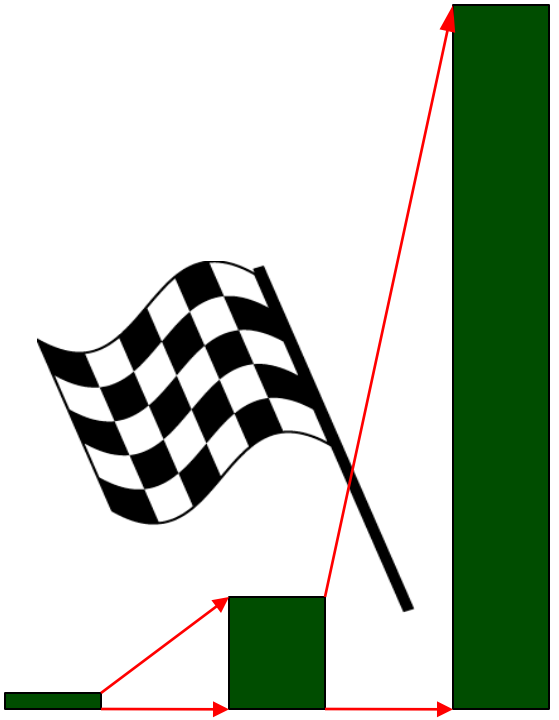
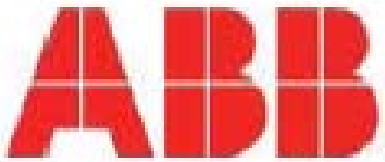


Table Top (Prior) | Prototype (ARPA-E) | Demo (Private $)

Grid Storage Program Breakout

Spotlighters



Industrial Panel

Focused Networking